Tensile Properties Distribution of Coir Natural Fiber Using Weibull Statistics

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ABSTRACT

In current time, most of the composites based on polymer resins reinforced with natural fibers than synthetic fibers for environmentally friendly consideration. This work investigate the study of tensile properties distribution of coir natural fiber by using Weibull statistics to quantify the degree of variability in fiber strength. Single-fiber tensile and microscopy tests were performed to determination the tensile properties (tensile strength and modulus of elasticity) and fiber cross-sectional area respectively. The experimental results showed that the coir natural fiber have a good tensile strength and modulus of elasticity of 89.91–237.46 MPa and 2.55-8.78 GPa respectively. The Weibull distribution indicates that the coir natural fiber have a high degree of linearity of $R^2 = 0.942$. The Weibull modulus for corn fibers was $\beta = 3.650$, gives a good variability in tensile strength.

Keywords: Coir natural fiber, Weibull analysis, Single-fiber, Tensile strength, Modulus of elasticity.

INTRODUCTION

Natural fibers are renewable materials which extracted from natural sources **[1]**. They are derived from plants, animal, and minerals but the most used are the plants ones because of their high availability and renewability in short time comparison to others **[2]**. Plants fiber can be divided into six groups: bast, leaf, seed, fruit, wood, and grasses **[3]**.

In contrast to synthetic fibers such as glass, carbon, and Kevlar, natural fibers are used in limited quantities as reinforcement in the field of polymer composite applications because there are several problems in using these natural fibers for creating high performance composites which delay wider usage of such materials especially in structural applications. The problems are: natural fibers have a large variability in their mechanical, chemical, and physical properties from batch to batch, the variability in geometry in fiber diameter, non–uniform of surface characteristics, limited fiber length (very short fibers), and some natural parameters such as soil fertility, age, and time of harvest **[4]**.

Coconut is the tropical plant and a member of the Areceac (palm) family **[5]**. Coir is the scientific name of coconut fiber **[6]**. Coir is a coarse fruit fiber extracted from the tissues surrounding the seed of coconut palm (husk of a coconut) **[7]**. Coconut fibers are found between the internal hard shell and the outer coat or husk of a coconut seed as shown in Figure (1). The husk of a coconut seed is consist of 30% fiber weight and 70% weight of pith material **[7]**. Cellulose, hemi-cellulose, and lignin are the three main content of coir fiber **[8]**. Due to their high lignin content, coir fiber is consider one of the hardest natural fibers **[9]**. The individual coir fiber cells are narrow and hollow as shown in Figure (2) with thick walls of cellulose. They are pale when immature, but with time become hardened and yellow in color due to a layer of lignin is

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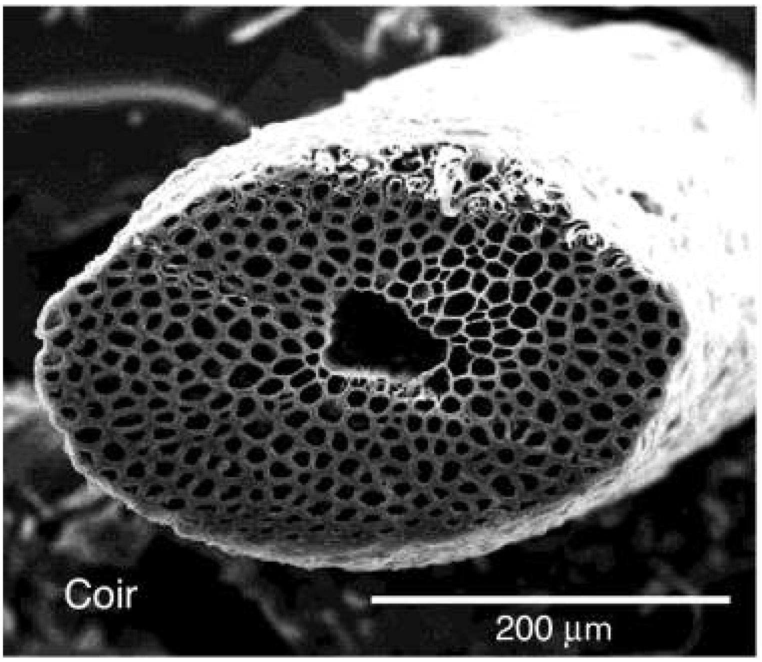
deposited on their walls **[10]**. Each fiber cell is about 1mm long and from 10µm to 20µm in diameter **[11]**. The length of coir fivers are varying from 100mm to 200mm **[12]**. Coir fibers is suitable to be used as reinforcement in different composite materials because it has several advantages such as: lightweight, strong, low thermal conductivity, heat resistance, salt water resistance, cheap, and easily extracted **[13]**.

The main purpose of this work is to get performance of coir natural fibers in order to get design high performance of biocomposites applications.



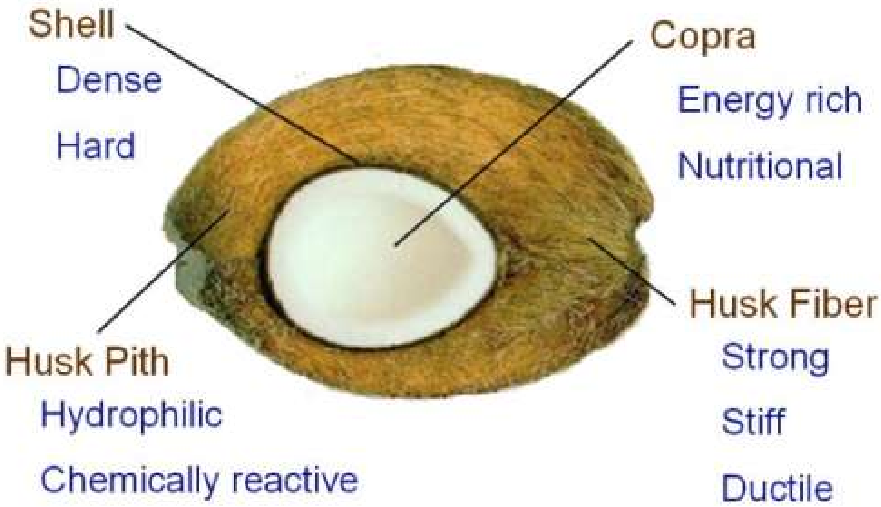


Figure (1): Parts of coconut seed [14].

Figure (2): SEM structure of coir fiber [15].

Weibull Statistics

Weibull analysis is the best statistical tool that used for explaining the brittle behavior of materials such as glass fibers **[16]**, which is based on the assumption that failure at the most critical flaws leads to total failure of the specimen **[17]. Theses** defects create randomly along the length of the fiber **[4]**. Recently this method has been used to analysis the properties the tensile properties of natural fibers such as jute **[18]**, hemp **[19]**, flax **[20]**, bamboo **[21]**, sisal **[22]**, and cellulose **[23]**. In this study, Weibull two parameters analysis was performed.

For coir fiber, the failure stress were ranked from minimum to maximum is determined from the following equation **[24]**:

$$P(\sigma_f, L) = 1 - exp\left\{-\frac{L}{L_\circ}\left(\frac{\sigma_f}{\sigma_\circ}\right)\right\}^{\beta} \quad \dots(1)$$

Where P is the probability of failure of a fiber length L at a stress less than or equal to σ. The constants σ^o and β are the scale parameter (characteristic strength of life) and the shape parameter, respectively. The scale parameter corresponding to the fracture stress of the fiber. m is the shape parameter, also called the Weibull modulus. L^o is the reference length (the minimum length to find a flaw); usually it is considered as unity or as the same length as the scale parameter or as the same length as the scale parameter so that to simplify the calculations **[25]**. The two Weibull parameters scale parameter σ^o and the shape parameter β can be estimated statistically as follows **[4]**:

$$E(\sigma_f) = \sigma_\circ \Gamma\left(1 + \frac{1}{\beta}\right) \quad \dots(2)$$

and

$$D(\sigma_f) = \sigma_\circ^2 \left\{ \{\Gamma\}\left(1 + \frac{1}{\beta}\right) - \left[\Gamma(1 + \frac{1}{\beta}\right]^2 \right\} \quad \dots(3)$$

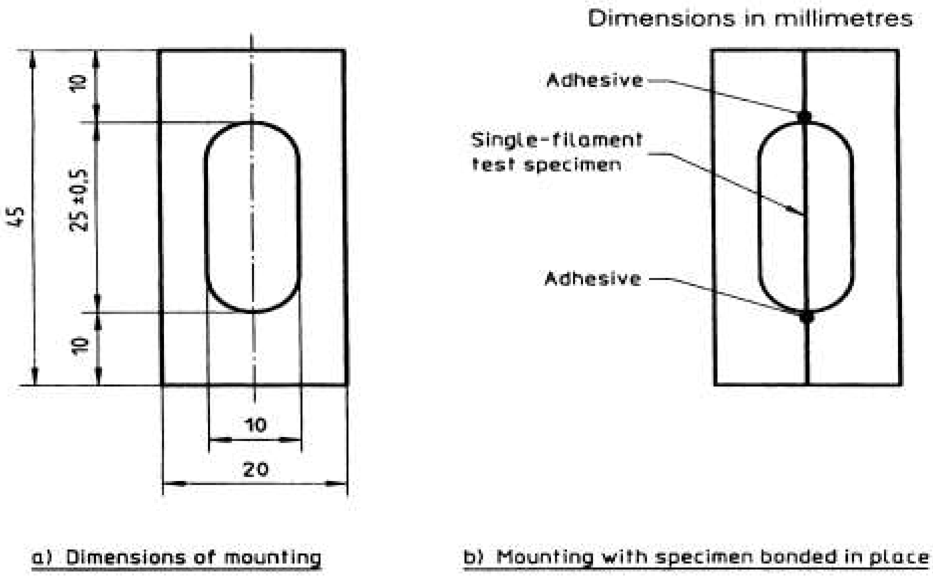
Where $E(\sigma^o)$ and $D(\sigma^o)$ are the mean and variance of random variable respectively. Γ is the gamma function.

Rearranging the two parameters Weibull distribution by taking twice the natural logarithm resulted in the following equation **[26]**:

$$ln\left(ln\frac{1}{1-P}\right) = \beta\, ln(\sigma_f) - \beta(\sigma_\circ) \quad \dots(4)$$

A plot of ln(σ) versus ln(ln(1/(1-P))) should give a straight line. The Weibull parameter and the shape parameter can be calculated from the slope and y – intercept of this line, respectively.

The



probability of fiber failure P is obtained using Bernard's correction **[27]**:

$$\boldsymbol{P} = \frac{\boldsymbol{i} + \mathbf{0.4}}{\boldsymbol{n} + \mathbf{0.3}} \qquad \dots(\mathbf{5})$$

Figure (3): A geometry of single–fiber test specimen according to BS ISO 11566 [28].

where i is i^{th} number in ascendingly ordered strength data of the sample and n is the number of samples in each group

Experimental work:
Materials Used

Coconut fruit were obtained from local shops (Glasgow - Scotland), the fibers were extracted from the fruit and then dried at 37 *°C* for 240 hours in an incubator (Sanyo MIR262, Japan) at School of Engineering- University of Glasgow-Scotland.

Single – Fiber Tensile Test

Individual fibers of coir fibers in a natural dry conditions with a constant gauge length of 25 mm and fiber length of 45 mm were tensile tested according to the BS ISO 11566 as shown in Figure (3) **[28]**. Sample mounts were made from a stiff white card sheets frame (delivered from GE company – Birmingham – UK). A single filament test specimen was placed over the center of the mount slot and one end of the fiber was temporarily attached to the mounting with a piece of adhesive tape. The fiber was lightly stretched across the slot and fixed the other end of the mounting with another piece of adhesive tape. To fix the fiber as straightly as possible between the clamps, a drop of glue was applied to the specimen at each end of the mounting slot as shown if Figure (4). The mounting was clamped in the grips of a Zwick / Roell materials testing machine (model Z250, Germany), fitted with a 5 N load cell, so that the specimen was aligned with the loading axis of the test machine and then card sheet sides where carefully cut in the middle as shown in Figure (5). The crosshead speed of the machine was 1 mm / min. which were performed at ambient conditions.

The load-displacement curve was recorded during the test. At least 11 successful tests were performed for each fiber type to allow Weibull analysis is to be applied, excluding fibers that broke near the edge of the clamps.

Figure (4): Stiff card sheets frame corn fiber sample for Single–fiber tensile test.

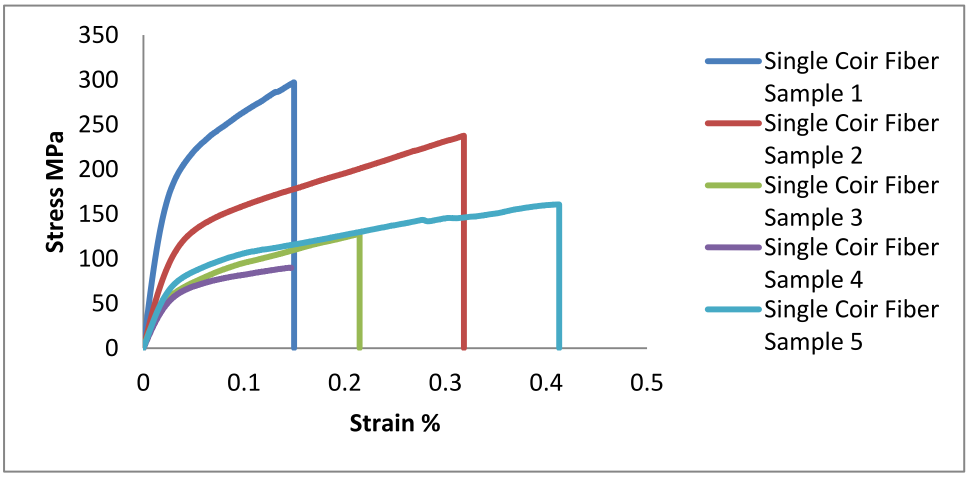


Figure (5): Single-corn fiber mounting test specimen during the test.

Determination of Single–Fiber Diameter

Before applying the single–fiber tensile test, the same single filament mount test specimens for each type of natural fibers that used in this test were used to determination of diameter of these fibers according to BS ISO 11567 – Method B **[29] u**sing Olympus microscope CX31–100AS (Olympus Scientific Solutions Americas, Japan).

The following equation was used to determination the diameter of coir fibers **[29]**:

$$d = \frac{N_r}{n} \quad \ldots (6)$$

Where *d* is the diameter of fiber, *Nr* the graduations number on the drum, and *n* the calibration constant.

Results and Discussion

Single–Fiber Tensile Test

The typical load – displacement curves for coir natural fiber are shown in Figure (6). These curves shows that the tensile load increased proportionally with increasing strain until the point of ultimate load, which is the maximum load on the stress–strain curve. At this point the coir fiber broke and exhibited brittle behavior with some of yielding for coir fibers.

The modulus of elasticity is the slop of the stress – strain curve was determined in the elastic region of the curve. For coir fibers, the values of the Young's modulus in the range of 2.55-8.78 GPa,the tensile strength between 89.91–237.46 MPa, and the strain to failure from 14.96–52.85 %.

Figure (6) Load–displacement curves of selected coir naturals fibers.

Weibull Analysis

The Weibull plot of tensile strength of coir natural fibers of 25 mm gauge length is shown in Figure (7). By applying the least squares method, the linear relationship between ln (σf) and ln (ln (1/(1-P))) is determined.

From this figure, the R2 coefficient of coir fibers is 0.942 respectively. The values indicates a high degree of linearity. Table (1) shows the statistical parameters of the Weibull distribution of coir natural fibers obtained from Figure (6).

Figure (7): Weibull distribution coir natural fiber tensile strength of 25 mm gauge length.

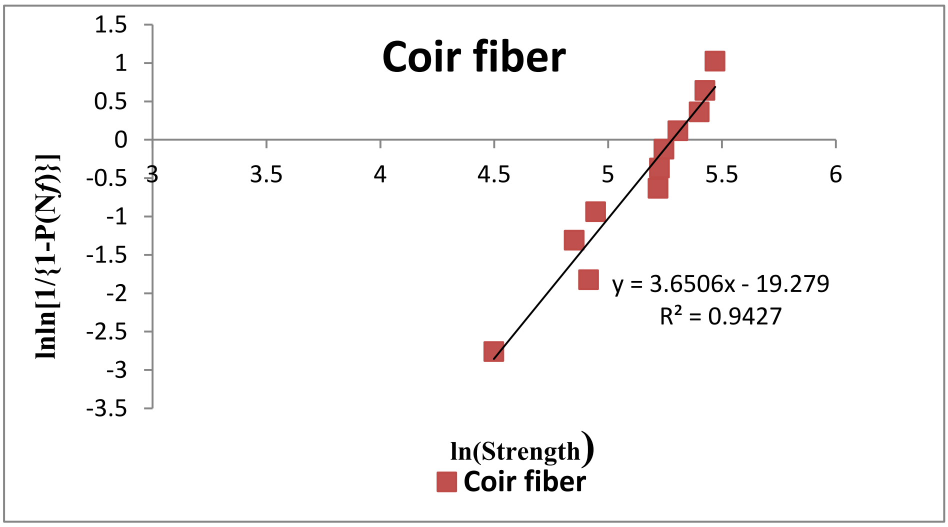


Table (1): Single–fiber tensile test results of selected corn and coir natural fibers.

Fiber	*Average Young's modulus GPa*	*Strain to failure (%)*	*Weibull modulus*	*Average Tensile Strength MPa*	*Average fiber diameter μm*
Coir	5.50	28.9	3.650	178.48	245

The Weibull modulus for corn fibers is β = 3.650, gives high variability in tensile strength. For synthetic fibers, the Weibull modulus between 1-15, while in most common natural fibers types which intrinsically have more variation in properties lie in the range of 1-6 **[29]**. The reasons of this large scatter in tensile strength of coir fibers are related to the 11 randomly selected coir fibers have a large variation in fiber diameter (190-320 µm) due to the distribution of flaws or defects on the coir fiber surface is more severe (more roughness).

CONCLUSIONS

1. The tensile properties of coir natural fiber have been studies using Weibull analysis.
2. The Weibull tensile strength distribution for coir natural fiber has a higher degree of linearity.
3. The experimental data found that the Weibull modulus of coir natural fiber lies in the range of 1-6 for most types of natural fibers.
4. The experimental data indicates that the coir natural fiber have a good tensile strength and modulus of elasticity**.**

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